AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

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PRELIMINARY HAZARD ANALYSIS

FOR THE

BRAYTON ISOTOPE GROUND DEMONSTRATION SYSTEM
(INCLUDING VACUUM TEST CHAMBER)

Prepared in Support of ERDA Contract E(04-3)-1123

by

AiResearch Manufacturing Company of Arizona

November 30, 1975

75-311665

DISCLAIMER

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This Preliminary Hazard Analysis (PHA) of the BIPS-GDS is a tabular summary of hazards and undesired events which may lead to system damage or failure and/or hazard to personnel. The PHA reviews the GDS as it is envisioned to operate in the Vacuum Test Chamber (VTC) of the GDS Test Facility. The VTC and other equipment which will comprise the test facility are presently in an early stage of preliminary design and will undoubtedly undergo numerous changes before the design is frozen. This PHA and the FMECA to follow are intended to aid the design effort by identifying areas of concern which are critical to the safety and reliability of the BIPS-GDS and test facility.

A PHA was previously prepared on the BIPS-FS (Ref. AIRPHX Report 75-311629 dated October 31, 1975). Many hazards/undesired events identified therein also apply to the GDS, but have generally not been repeated. For example, possible contamination of the working fluid by offgassing of alternator organic material is of concern during operation of the GDS, but has not been repeated herein because the problem will be adequately treated during development of the Mini-BRU. On the other hand, contamination of the working fluid through the presence of residual contaminants is repeated since charging of the system with "pure" working fluid gases will be an important step in preparing the GDS for operation.

The PHA uses the following symbols to identify the "Program Phase" of interest:

PRE - GDS preparation; Pre-Startup of BIPS

GOP - GDS-BIPS Operating

The following symbols have been used under the heading "Hazard Category" to denote the potential result of the identified hazard/undesired event. They are the same symbols used in the PHA of the IBFS and are consistent with the hazard level defined and established by MIL-STD-882, "Requirements for System Safety Program for Systems and Associated Subsystems and Equipment." Each hazard category is equated not only to system damage, but to personnel injury as well. However, with the BIPS-GDS (and to a lesser extent with the BIPS-FS) most hazards are related to system damage or failure. (The first column under "Hazard Category" denotes the estimated severity before "Corrective Action/Minimizing Provisions" have been identified; the second column indicates the estimated potential for eliminating or minimizing the effects).

I - Negligible - will not result in personnel injury or system damage

II - Marginal - can be counteracted or controlled without injury to personnel or major system damage

III - Critical - will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival

IV - Catastrophic - will cause death or severe injury to personnel or system loss

(It should be noted that personnel hazards associated with the BIPS-GDS are virtually non-existent, assuming that normal caution is exercised in working with the equipment comprising the system and its test facility).

A number of possible undesired events which will result in shutdown of the BIPS-GDS have been categorized as "II - Marginal" since major system damage will not occur. However, these unscheduled shutdowns are highly undesirable and all economically feasible precautions must be taken to preclude these interruptions during performance and endurance tests.

Comments and suggested changes and additions should be forwarded to AiResearch Manufacturing Company of Arizona, attention: L.G. Miller, P.O. Box 5217, Phoenix, Arizona 85010.

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PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION BIPS-GDS (includes Test Facility)

NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
1	Contamination	PRE-GOP	Residual contaminants in w/f gases.	Contamination may severely embrittle C-103 structure; long term creep tests required to determine magnitude of C-103 strength degradation.	II-IV	I	High quality Xe/He required as working fluid; required chem analysis as part of QA acceptance; use getter in fill line; re-use acceptably "clean" bottles and keep above minimum pressure.
2		PRE-GOP	Oxides, nitrides, hydrocarbons, metal oxides, or water vapor may be present in MBR, Mini-BRU, ducting, bellows, HRHX, or HSA.				Cleaning procedures for pre-storage and post-assembly of components must be developed to eliminate levels of contaminants determined to be harmful to C-103.

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NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
3	Contamination (Contd)	PRE-GOP	Sources outside w/f loop: Carbon, CO/CO_2 from EHS		II-IV	I	Disassemble EHS, bakeout graphite (1500°C, ∿36 hrs, $\leq 3 \times 10^{-4}$ torr); reassemble, store in inert atmosphere, load HSA in inert atmosphere, seal. Consider using super alloy turbine plenum and ducting for GDS; substitute a simple heat source simulator for HSA/EHS. Provide cladding for EHS - Pt 3008 or silicide coated C-103 "can".
4			Oxygen, nitrogen, water vapor from environment, insulation, and structure.				Provide cleaning and decontamination of components; pump down and bake out vacuum chamber after GDS is installed but prior to start up.

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NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
5	Contamination (Contd)	GOP	Sublimation of braze material used to attach internal fins to ducts of HRHX (cooler)		II-IV	I	Low temperature (260°F); however, braze material must be carefully selected.
6			Backflow of air, other contaminants in event of vacuum pump failure or power outage				Install fast acting gate valves to seal pump inlets (automatically triggered by loss of pump, vacuum, or facility power); use redundant gate valves located between pump inlets and vacuum chamber interface. (Turbo-molecular pump discharges to roughing pump which discharges to atmosphere); shroud pump discharges in inert gas to minimize chamber contamination should significant backflow occur prior to valve actuation.

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NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
7	Contamination (Contd)	PRE	Inner surface of vacuum test chamber rough; contains oil or other contaminants	Degrades rate of outgassing and attainment of desired vacuum ($\leq 10^{-5}$ torr)	II-IV	I	Achieve smooth, polished interior surface; clean surface with appropriate solvents. (Caution - Use of solvents introduces health hazards. Wear mask - and danger of explosion - use extreme care).
8	Leakage of GDS working fluid	GOP	Failure of ducting joints and/or bellows; cracks in ducts, bellows, as a result of high stresses.	Leakage or loss of working fluid, resulting in degradation of performance or complete system failure.			Close QA control is necessary to assure quality of welds and ducts.
9							Double containment weld joints should be considered where feasible.

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10	Leakage of GDS working fluid (Contd)	GOP			II-IV	I	Correct design of bellows to compensate for centerline misalignment due to thermal expansion and lateral deflection will be an absolute necessity, as is the development and demonstration of highly reliable bimetallic joints (C-103 to Hast-X)
11							Assure proper alignment of components at time of assembly of GDS; perform stress analysis to determine maximum tolerable misalignment.

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12	Leakage of GDS working fluid (Contd)	GOP			II-IV	I	Addition of residual gas analyzer (similar to a mass spectrometer) to the vacuum test chamber can serve to warn of leaks in GDS by detecting xenon and helium from working fluid. (The RGA can also identify source of other leaks or vacuum test chamber introduced contaminants such as argon from seal or chamber penetration, lubricant from turbomolecular pumps, roughing pumps, and miscellaneous outgassing). Consider use of hot getters inside tank near seals and penetrations.

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13	Leakage of GDS working fluid (Contd)	GOP	Leak at duct/ manifold interface or HRHX (cooler) inlet/outlet manifold due to defective braze; leak in copper duct of HRHX due to assembly defect.	Leakage or loss of working fluid.	II-IV	I	QA control should preclude; proof pressure test should detect.
14	Loss of vacuum in vacuum test chamber		Interruption of electrical power to vacuum pumps.	Loss of vacuum in tank results in oxidation of super alloy multi-foil insulation, loss of emissivity of insulation, contamination of C-103; and degradation of BIPS performance.			Consider the use of dedicated power generators with redundancy, and/or backup batteries, vice commercial power. Provide emergency system designed to automatically close gate valves sealing pump inlet ports; introduce positive pressure ($\sim$1.1 atmos.) argon into tank to protect C-103 in GDS if vacuum

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14	Loss of vacuum in vacuum test chamber (Contd)	GOP			II-IV	I	loss is sufficient to endanger the columbium and/or insulation.
15			Vacuum pump failure				Use redundant turbomolecular pumps (two minimum, operating in parallel; consider third pump in standby; single pump capable of sustaining 10^{-5} torr, once attained). Incorporate sensors which will close gate valves on pump inlet in event of individual pump failure, thereby protecting vacuum chamber from intake of contaminants.

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NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
16	Loss of vacuum in vacuum test chamber (Contd)	GOP	Leakage of welds, seals of chamber inlet and feedthrough ports, and other mating surfaces.		II-IV	I	Use of state-of-the-art high vacuum technology should preclude leakage of magnitude sufficient to seriously affect chamber environment. (Conceptual protection system will sense loss of vacuum and take measures to protect system from damage).

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NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
17	Damage to GDS	GOP	Controls malfunction; loss of load	Overspeeding of Mini-BRU, resulting in failure of bearings and stoppage of rotating group (Maximum attainable speed has been calculated to be 105,000 rpm which is well below burst speed for rotor; bearings would probably fail before this speed is attained).	IV	I	Proper design of controls should preclude. Close quality control necessary to preclude failures which could result in overspeed condition (e.g., loss of electrical and/or parasitic load(s)). (Preliminary design of test facility includes turbine bypass valve system intended to automatically open and shut down engine if overspeed condition is present, thus affording system protection).

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18	Damage to GDS (Contd)	GOP	Underpressure of foil bearings resulting from loss of working fluid.	Bearing seizure	IV	I	Design and quality control must assure the integrity of the working fluid loop containment. (Preliminary design of test facility includes turbine bypass valve system intended to automatically open and shut down engine if underpressure of foil bearings condition is detected, thus affording system protection).
19		PRE	Inadvertent overpressuring of entire working fluid loop.	Damage to heat exchangers and/or ducting	II-IV	I	Preliminary design of test facility includes, as a safety feature, a pressure relief valve between Mini-BRU compressor outlet and recuperator H.P. inlet. Consider use of audible and/or visual signal to warn of pressure exceeding nominal limit.

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20	Damage to GDS (Contd)	GOP	Bypass leak in MBR, cooler failure, etc.	Overtemperature condition at compressor inlet resulting in slight loss in performance but no permanent damage.	II	I	Implement control safeguards (warning lights, alarms, shutdowns) to alert/ warn/shutdown system when these conditions are encountered. (Preliminary design of test facility includes turbine bypass valve system intended to automatically open and shut down engine if overtemperature condition is detected at compressor inlet, turbine inlet, foil bearings or alternator, thus affording system protection).
			Various	Overtemperature condition at turbine inlet, foil bearings, or alternator resulting in possible serious damage and shortened life, depending on severity of overtemperature.	III-IV	I	

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NO.	HAZARD/UNDESIRED EVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
21	HRHX (Cooler) fails to perform as required	GOP	Leakage, rupture of copper coils containing coolant	Degradation or complete loss of HRHX efficiency, resulting in gradual or rapid failure of BIPS through overtemperature	II-IV	I	Correct dsign, proper selection of materials, and QA control should preclude.
22			Copper coils (brazed to HX ducts) separate from ducts	Degradation of HRHX efficiency	II	I	Proper assembly, brazing, should preclude; minimal areas of separation can probably be tolerated.
23			Electrical or mechanical failure of refrigerant pumping system	Shutdown of BIPS-GDS	II	I	Incorporate redundant pumps (two in parallel) powered by dedicated power (with redundancy) vice commercial power. Incorporate emergency back-up system which would introduce water at tap pressure into cooling coils for

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23	HRHX (Cooler) fails to perform as required (Contd)	GOP			II	I	temporary cooling during repair and/ or resumption of normal cooling.
24	Unscheduled shutdown of GDS		Failure of BIPS	Test delay	II-IV	I	PHA-IBFS (AIRPHX Report 75-311629) tabulates various possible causes for failure; FMECAs will identify failure modes and effects.
25			Test facility electrical power loss	System shut-down	II	I	Consider the use of dedicated power gen-erators with redun-dancy and/or back-up batteries, vice com-mercial power, for all ancillary equip-ment, EHS, control system, and monitor-ing equipment.

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26	Unscheduled shut-down of GDS (Contd)	GOP	Turbine bypass valve (TBV) fails open (preliminary GDS design incorporates a TBV-normally open, energized closed-which will open when predetermined unsatisfactory condition is sensed. Open TBV isolates turbine from working fluid flow).	Engine shut-down	II	I	Protection system is sensitive to valve failure (electrical or mechanical), to momentary power interruptions, and to open circuits in circuit which holds valve closed. Consider redundant valves in bypass duct to preclude single valve failure shutting down system. Consider use of normally closed valves with backup power supply for opening when shut down system is activated.

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27	Unscheduled shut-down of GDS (continued)	GOP	Turbine bypass valve commanded open by erroneous trouble signal.	Engine shut-down	II	I	Conceptual protection system incorporates "trouble" signals from following sensors for automatic shutdown: 3-Mini-BRU Overspeed 1-Compressor Overtemp. 1-HSA #1 " 1-HSA #2 " 1-Journal Brg. " 1-Thrust Brg. " 2-Alternator " 1-Journal Brg Low Pres. 1-Thrust Brg. " " 1-Loss of vacuum in Test Chamber.
				The manner of connecting the sensing system has yet to be determined. Care must be taken in circuit design to preclude single erroneous signals and malfunctioning sensors, transducers, comparators from shutting down system during test runs. For example, system may require "majority vote" (overspeed signals from at least 2 of 3 speed sensors) to shut down engine. Reliable design coupled with quality materials and assembly will be required to preclude false alarms and shutdowns.			